TATA ENERGY RESEARCH INSTITUTE
BANGALORE

ENERGY ASPECTS OF INDUSTRIAL FURNACES

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CONTENTS

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1.0 INTRODUCTION

Basically a furnace is a brick lined chamber, capable of holding/conveying the material to be treated, to which heat is applied by one of the various means so as to achieve the required final result.

Although furnaces are put to widely different uses and conditions may vary very much, the general principles are common to all. Depending on the type of heat input the furnaces can be broadly classified as

1. Oil fired furnaces
2. Coal fired furnaces
3. Gas fired furnaces
4. Electric furnaces

This paper focusses mainly on the oil fired and electric furnaces as the heat utilisation aspect for all the furnaces remains more or less same.

2.0 OIL FIRED FURNACES

In any furnace, the total heat of combustion of the fuel is dissipated in four ways:

1. By transfer to the 'process'. The 'process' can range from water in a boiler to bricks in a kiln or a metal casting in a heat treatment furnace.
2. By radiation and convection losses from the structure of the furnace.
3. By heat loss in the hot flue gas.
4. By loss of unburnt fuel.

Of the above items, only (1) is desirable. In an efficient furnace, the losses (2,3 & 4) will be minimised.

Thermal efficiency of a furnace can be defined as the percentage of the fuels combustion energy that is transferred to the 'process'.

Thermal Efficiency, % = 100 -(% energy lost as flue gas enthalpy + % loss by radiation & convection
+ % loss as unburnt fuel)

For the most efficiently insulated furnaces operating near design capacity, radiation and convection losses account for no more than about 5% of the total combustion energy. For oil and gas fired furnaces, unburnt fuel losses should be insignificant (< 1%). Typical thermal efficiencies of various types of furnaces are depicted in Exhibit–1.

The following aspects have to be considered while studying any furnace in order to make it energy efficient .

2.1 COMBUSTION EQUIPMENT

The primary component of a combustion system is a burner/stoker. The burner must mix the fuel and the air in proportions that are within the limits of flammability as well as providing the conditions for steady continuous combustion.

By far the majority of industrial oil burners atomise the oil prior to combustion. To achieve satisfactory atomisation, the oil must first be brought to the burner at the correct pressure and viscosity as stipulated by the equipment manufacturer. A viscosity of 65/70 cSt is usually required and by the use of a temperature/viscosity graph the appropriate temperature may be determined.

The atomiser section of the burner has as its purpose to deliver the oil into the combustion chamber, sufficiently atomised, at the correct spray angle and size for the combustion chamber and in such a manner as to permit good air penetration and mixing.

Oil must be broken up into fine droplet form if it is to burn rapidly and the life of any single droplet in the combustion chamber is approximately proportional to the square of the initial diameter. The droplet diameters produced by the average industrial atomiser may vary from 20–500 microns with consequent variations in burning time or distance from the point of entry. In most oil firing applications small oil droplets with the correspondingly short combustion time are most desirable, but in some furnace work, a long flame may be required which invalidates the need for fine atomisation.

Where the atomising equipment is damaged or worn, or the atomising medium energy is inadequate, the size of droplets produced may well mean that the droplets do not have sufficient time to burn within the flame envelope. This results in partially burned, or carbonised, oil leaving the high temperature zone and being either deposited in the flue system or ejected to atmosphere. These particles are then the basis of what is known as 'stack solids'. Oil burners are classified into types according to the method used to atomise the oil. The various type and characters of burners in common use are depicted in Exhibit–2.

2.2 FURNACE DESIGN

Flow Pattern

The path taken by the gases flowing in the furnace can have a profound effect on its performance. It is well known that in furnaces heated by convection the quality of heating depends on uniform flow of gases over the stock. But even with the furnaces heated by radiation the flow pattern is important since the refractory surfaces themselves must receive heat from gases.

It is essential that the flame and gas flow patterns with in a furnace should give the required heat transfer pattern for which the following aspects should be considered.

1) Air and gas distribution to the furnace chamber and mixing, to ensure uniform heat release and constant atmosphere throughout the furnace width.

2) Flame path control to prevent burning of the stock or impact on the furnace refractories leading to rapid failure .

3) Static pressure control related to the furnace geometry to restrain air infiltration or blowout of the combustion gases.

Maldistribution

Bad distribution of flow can completely ruin the performance of a furnace. It can result from many factors, some in the design and some in the operation of the furnace. Some of these are discussed below:

Wrong location of waste-gas offtakes: These should in general be as far from the burners as possible; but their location is not critical with furnaces operating under slight pressure.

2. High velocity burners create a jet induction effect which can give rise to suction near a furnace opening and allow cold air to enter. This is particularly troublesome in the soaking zone of end-discharged reheating furnaces. It can, under different circumstances, assist in uniform heating of the furnace by entraining spend furnace gases into the freshly burnt gases issuing from the burner.
3. Flame impingement on the walls and roof can be caused by wrongly aligned burners, or impingement inside the burner casing of gas or air which is then swirled as it leaves the burner.
4. When air (or fuel) is supplied to several burners by a manifold, it is important that this be large enough to act as plenum chamber, otherwise the flow to some burners will be excessive and the others may be starved, resulting in a badly heated furnace.
5. A badly located load can spoil the operation of a good furnace by affecting the recirculation of gases.
6. *Location of Burners:* It is a generalization that the top of a furnace looks after itself since heat rises. With batch- type furnaces, in addition to locating the main burners lower in the walls, it is often useful to have a second set of low- capacity high-velocity burners that fire directly towards the load without impinging on it, so creating induction recirculation.
7. It is difficult to keep furnaces with a large turn-down ratio under pressure; under these conditions cold air can enter. If the process temperature is not too high, excess air becomes greater as the fuel flow decreases. This can be achieved by maintaining constant air flow and regulating the fuel flow. With some furnaces, steam or a neutral atmosphere, may be used to augment the gases.

Recirculation

The flow of gases round the charge can sometimes be promoted by careful location of the flues, but recirculation generally requires more positive action, such as the jet-induction effect or the provision of stirrer fans.

Where the furnace is essentially convection-heated, the recirculation is invariably fan-generated, and it is important that the volume recirculated should be adequate. The location of circulation inlets and outlets is then not critical and they can be quite simple. When complicated straighteners or flow-dividers are employed, it is usually an indication of too small a recirculation volume.

Structure storage heat losses

The heat requirement is influenced by the thermal capacity and conductivity of the structure, and the lightest construction consistent with optimum insulation, mechanical strength, refractoriness and replacement cost will minimise fuel consumption.

For a furnace in continuous operation the structure reaches temperature equilibrium, and the heat quantity stored in it becomes small in relation to the heat quantity conducted through it and dissipated from the external surface. Structure thermal conductivity is, therefore, of greater importance than its thermal capacity.

For a furnace operated intermittently, the structure is unlikely to reach temperature equilibrium and the heat stored in it will be repeatedly replenished and depleted according to the nature of the operating cycle. Although the thermal conductivity of the structure is still important, its thermal capacity must be held to a minimum.

The wall losses from a furnace depends on the thicknesses of the firebrick and of insulation, on the type of insulation and on the continuity of operation. The manner in which savings vary is shown below, which refers to wall losses only and not to the total heat consumption of the furnace.

REDUCTION OF WALL LOSSES BY INSULATION (%)

Thickness of firebrick wall (inch)	Continuous operation insulation		1 week cycle insulation	1 day cycle (6days/week) insulation
	2.5"	5"	2.5"	2.5"
4.5	62	76	58	25
9	46	65	36	18
13.5	38	57	20	14
18	35	53	15	12

Operational factors should be considered when determining the economic insulation (material and thickness). Many times the furnace needs frequent repairs, where the cost of insulation replacement should be taken into consideration; examples of these are where furnaces that are to be heated upto quickly after a prolonged shutdown, where very high skills are required for loading and unloading of the stocks, where furnace spalling is of frequent problem, and where salvaging of insulation is not possible.

Exhibit–3 gives comparative values of conduction and storage heat losses for various types of wall construction when applied to a high temperature furnace operated continuously and intermittently.

In each case, 340 mm dense firebrick is most expensive in terms of total heat losses and fuel consumption to satisfy them, and the percentage reductions in total heat loss indicate how each alternative construction compares to it.

Lowest fuel consumption would be obtained with 115mm super hot face insulation brick backed by 230mm insulating brick. For continuous operation 115mm firebrick with 230 mm insulating brick runs a close second and would be more resistant to impact damage.

Ceramic fibre with mineral wool backing insulation is an attractive and relatively new form of construction for furnace chamber walls and roof. It is attached to a light external steel casing and although the material is more expensive than refractory brickwork, the total construction costs are said to be less.

For a 70 tonne bogie-type annealing furnace, charge soak temperature 950–1000°C, intermittent operating cycle 12 hours/day, it was predicted that a 12 % saving in fuel consumption could be expected relative to similar

operation with a furnace constructed of 115mm insulating brick. It must be stressed that, for each type of construction, the dense firebrick bogie accounted for the majority of the storage heat loss.

Furnace Load Factor

When a furnace is held at operating temperature it has what amounts to a no load fuel consumption which must satisfy the structural heat transmission losses. If it is then put into production, additional fuel must be consumed to heat the stock.

Furnace performance is judged on the fuel consumed per unit of stock produced and is highest when the no load fuel consumption is shared amongst the greatest number of stock units.

Exhibit–4 gives a performance analysis for a small steel reheating furnace operating at various material throughput rates or load factors. The term "hearth" loading is a convenient means of expressing furnace load in a form which makes comparison with optimum practice easy. The significant item 'specific fuel consumption' expressed in gallons per ton of steel heated can be seen to decrease rapidly as furnace loading approaches optimum.

2.3 FURNACE OPERATION

1. Combustion

Combustion can be defined as rapid chemical combination of oxygen with combustible elements of fuel. There are two combustible elements of principal significance in commercially used fuels, namely carbon and hydrogen. Sulphur is also present in some fuels. This is usually of minor significance a source of heat but may be of major concern in terms of corrosion and environmental problems. More aspects related to combustion are discussed separately in the section dealing on Steam Generation.

2. Furnace Pressure

Fuel fired furnaces should always be operated under a slight pressure since this tends to even out the flow of gases inside the furnace and prevents ingress of cold air round the doors and other openings.

A reasonable pressure to aim for is about 2.5 Pa (0.01 in w.g), and this should be measured at the hearth level to avoid the buoyancy effect. If the furnace is not kept under positive pressure, it is possible for the gases to short-circuit straight to the flues, thus increasing the heat loss whilst spoiling the heating of the charge.

If the furnace is gas-tight as well as the doors, burner-lighting holes and flue offtakes, then a furnace can be operated at high pressure. The furnaces, however, must be lighted at atmospheric pressure and sealed (except for the flue) before increasing the flow to full value; the pressure may then be increased to the required level by use of the damper.

It should be emphasised that furnaces using recirculation must be made completely gas-tight, otherwise air will be drawn in at some points and forced out at others.

3. Controlling Excess air

The effect of excess air on furnace stack loss is shown in Exhibit–5. Too little air can also cause a major heat loss. Savings achieved by reducing excess air can be hard to estimate. If the air is reduced but the fuel rate

remains the same, the flame temperature will increase and provide a more rapid heating rate and an energy-saving shorter cycle. However, the reduction in excess air will also raise the stack temperature and thus increase stack loss.

If air and fuel are adjusted to maintain the stack temperature, furnace gas velocity will decline and turbulence in the furnace will be reduced. As a result, the heat transfer rate to the stack will suffer, which can increase cycle times. It is thus suggested to calculate the heat balance under the new operating conditions to determine the net effect of the change.

2.4 HEAT RECOVERY FROM STACK GASES

Heat can be recovered from exhaust stack gases in several ways, including heat exchangers and/or recuperators. In most cases, the recovered exhaust is used to preheat combustion and excess air.

The percentage fuel savings achieved by preheating combustion air for various flue gas temperatures are given in Exhibit–6. The temperature to which combustion air can be preheated is somewhat limited by the burners fitted to the furnace. To take full advantage of this measure, it is sometimes necessary to replace the existing burners in addition to fitting a heat exchanger to recover the heat.

The combination of preheated combustion and secondary air can give rise to fuel savings as follows:

1.	Temperature of all the combustion air (^{o}C)	100		150		200	250
	Approximate savings in fuel (%)	4.6		6.8		9.1	11.4
2.	Passing 5% of combustion air as cold air through the burner and remainder as secondary air (^{o}C)		375		450		500
	Approximate fuel savings(%)		15.9		17.8		19.7

Factors to be considered

Once a source of waste heat has been identified and quantified there are a number of factors that need to be assessed in order to determine the feasibility of the waste heat recovery system.

a) Location

The location of heat recovery systems can be classified into 3 categories.

i) *Compact Systems* — Where the heat is recirculated around the system to reduce the quantity of cold incoming make-up air or combustion air e.g., paint, drying ovens and self-recuperative burners.

ii) *Local Transfer* — Where the source and use of recovered heat are close together.

iii) *Distant Recovery* — Where the source, recovery and application are some distance apart.

b) Grade and state of Medium

Two general distinctions can be made in grades of heat:

* High Grade Heat – source temperatures above 250°C, the majority above 750°C.
* Low Grade Heat – source temperature below 250°C, and mainly between 0°C to 100°C.

Clearly, the identification of grades is fairly straight forward but is an important step since it provides a guide to the technology we will need to use in the system. With high grade heat there will be a choice between carbon steel, stainless or ceramic material. With low grade heat, decisions will have to be taken on the need to use heat pumps or more sophisticated heat exchangers with increased areas and alloy metals.

In many low grade heat projects involving saturated gases a major benefit lies in recovering energy present in the form of latent heat. In some cases an extra benefit may be available from this approach because condensed liquids can be recovered, treated and reused.

c) Quantity of Heat

When assessing the quantity of heat available for use, it is just as important to quantify the consumption of recovered heat by the proposed application. If the application already has its own source of heat, then the introduction of recovered heat does not present such a great risk because a short fall in recovered heat either due to inaccurate assessment or unforeseen difficulties can be made-up by the existing heating system.

d) Purity

The source of recovered heat should be examined for the following contaminants:

* Particles – sizes and nature
* Acidity
* Dryness
* Toxicity

Shell and tube type heat exchangers will tolerate a larger and higher particle concentration than plate type exchangers. Acidity and dryness will only become a corrosion problem if the exhaust temperatures fall below the dew point of the gas. In assessing this aspect it is important to estimate the exhaust temperature from the system and not solely in the exit from the exchanger.

e) Pattern of availability and use

The pattern of availability and the pattern of use of recovered heat must be considered. Incompatibility occurs due to:

* Cyclic operation of the source of application
* Seasonal variation in the process source

Finally the actual performance of source and application processes should be measured. Use of production data or design data will often be inadequate for detailed feasibility because it does not represent the total picture of what happens in practice. Fluctuations and stoppages in production must be identified so that adequate controls and bypasses are incorporated into the basic design.

Equipment Available

A review of heat recovery devices along with description and application is depicted in Exhibit–7.

2.5 FURNACE INSULATION

The heat losses affected by insulation are:

1. The escape through furnace brick work of heat that is subsequently dissipated by convection and radiation from the outer surfaces of the structure.
2. The storage of unnecessary heat in the structure. With proper insulation, these losses can be substantially reduced but with insufficient insulation or none at all, such losses can be in excess of 25 %. Surface losses are dependent on wall thicknesses and materials of construction, also on the temperature in the furnace and on the area of the outer wall surface.

In continuous or long term cycle furnaces, the problem is to prevent the escape of heat through the walls and roof. In intermittent or short time-cycle furnaces, it is to reduce the heat storage loss while not neglecting to reduce the external surface loss.

There is a mistaken impression that intermittent furnaces cannot be insulated because the interior, including the load, cannot be adequately cooled between cycles. With hot face insulation and particularly with ceramic fibre materials this problem has been surmounted.

A temperature of 40 to 70 °C for a furnace operating in excess of 350°Cindicates that the losses are reasonable. A temperature of 100°C or higher means that the losses are probably quite large. An estimate of energy loss per unit of area per hour as a function of outside will temperature is shown in Exhibit–8.

Exhibit–9 compares the operating temperatures of various insulating materials, including ceramic fibres.

Ceramic Fibres

More recently, ceramic fibres have become available for hot face furnace insulation. Types are available for continuous operation at maximum temperatures of around 1600°C.

Commercially produced ceramic fibre consists essentially of Alumina(43–95%) and Silica (5–57%) with traces of other elements. Ceramic fibres are not wetted by molten metals and can be used in direct contact with aluminium, lead, zinc, copper and alloys of these materials.

The chemical attack resistance of ceramic fibres is very good, being resistant to most furnace atmospheres, to oil, steam, water and most acids and many alkalies. The two major forms in which ceramic fibre is at present used in industry are blankets and modules.

Advantages of Ceramic Fibres

* Low heat transmission
* Low heat storage
* Light weight construction
* Resilience
* Low thermal expansion

* Ease of installation and repair
* Maximum operating temperature
* Low design outer face temperature (Energy losses increase in an exponential manner with the temperature of the outside of the furnace)

Case Studies

a) Continuous reheating furnaces in the steel industry operating upto 1350°C have been lined with ceramic fibre modules resulting in a published saving of 15 %.

b) An intermittent bogie hearth furnace in the heavy engineering industry operating up to 1050°C has returned recorded fuel savings of over 30% after ceramic fibre insulation.

2.6 STOCK PREHEATING

In continuous steel billet or slab pusher type reheating furnaces, the hot combustion products leaving the main heating zone pass through a preheating zone. In passing through it, their temperature will be reduced from say, 1300 to 700°C the heat abstracted being equivalent to 37% of the net heat of fuel fired (at 30% excess air). The stock temperature will rise from 25– 400°C and a third of the stock heat requirement will have been supplied merely by degrading the heat content of the main heating zone waste gas.

If it takes 450 litres of fuel oil to produce a given steel output without stock preheat, then with preheat the same output quantity could be obtained for a fuel consumption of around 290 litres, a saving of 160 litres in every 450 litres.

A gas fired aluminium melting and holding furnace has a rated metal output of 900 kg/h operated at a mean specific fuel consumption of 470 litres/kg metal, when ingots and scrap were charged direct into the molten metal bath. When the waste gases are discharged through a tower into which the cold metal is charged, a most effective form of stock preheating is obtained. Specific fuel consumption falls to around 280 litres/kg metal – resulting in 40 % reduction in fuel consumption.

2.7 INCREASING OXYGEN LEVEL

Substituting commercial oxygen for combustion air reduces the volume of heat-absorbing nitrogen flowing through the combustion process, and thus reduces losses. Potential savings are shown in Exhibit–10. The normal practice is to increase oxygen levels from 21% to 25–30%.

A full feasibility study should be conducted to determine all implications of this measure, including the cost and availability of oxygen, the flammability limits, and extra safety precautions that are needed.

2.8 TESTING FURNACE EFFICIENCY

To test the furnace efficiency the following measurements are required.

* Fuel usage rate
* Temperature of operation
* Fluegas composition and quantity.

After all these measurements, an energy balance of the furnace can be done to quantify the various losses associated with the process. A typical energy balance is shown in Exhibit–11.

2.9 REASONS FOR LOW ENERGY EFFICIENCIES IN VARIOUS INDUSTRIAL FURNACES

a. Obsolescence of design and age of furnace as also of the combustion device was a major reason for very low efficiency of the equipment. It is not possible to effectively retrofit energy conservation equipments on them. Since furnaces of low efficiency could nevertheless be based for production, they continue to be operated despite.

b. The overall layout and environment of the plant impose limitations on the possible energy conservation achieved through proper storage and handling facility for fuel.

c. The nature and magnitude of the energy requirement in the manufacturing process also decides the extent of heat recovery.

d. The nature of process and level of technology employed are found closely related to the degree of mechanisation and automation. It was generally recognised that with degree of mechanisation and automation, operational losses and idle periods on account of damages occuring due to manual handling were considerably reduced. This in turn resulted in heat losses. Moreover better monitoring and control of process parameters help enhance energy efficiency of equipment.

e. In adequate availability and performance reliability and servicing of instruments (which has to operate under changing conditions, specially in a metal forging/forming/casting unit) are some of the factors which increase energy consumption. This in turn results in reluctance to install adequate instrumentation for enhancing energy efficiency of equipment and process.

2.10 CASE STUDY

Heat balance for a conventional oil fired melting furnace (2 tonne aluminium) with out heat recovery unit is given below:

Useful heat	=	12 %
Losses due to Leakages	=	9 %
Losses due to Charging	=	15%
Storage loss	=	7%
Flame out	=	6%
Radiation loss	=	3%
Stack combustion loss	=	48 %

The following observations and recommendations were arrived at after analysing the energy balance and the furnace operation.

1. Proper production planning and hence reducing cooling losses during storage and superheating.
2. Dampers at the blowers to be placed for combustion control and to reduce natural losses during shut down.

Also provide dampers at exit and close all openings. These also reduce cooling losses and to maintain the furnace pressure.

3. Mechanised charging and reduced charging time which reduces heat loss and damage to the furnace. (Presently manual charging takes around 1 Hour)

4. Proper control of combustion by modulating firing rates during initial heating, melting and superheating.

Expected heat balance after implementation of recommendations

1. Useful heat	=	32%
2. Heat loss due to leakages	=	6%
3. Charging losses	=	4%
4. Storage losses	=	4%
5. Flame out	=	3%
6 Radiation losses	=	3%
7. Stack losses	=	48%

The implementation of the recommendations would not only reduce specific fuel consumption but also improve productivity. Approximate annual savings expected are around Rs. 10 lakhs.

3.0 ELECTRIC FURNACES

The use of electricity for heating can seldom be justified on a straight specific fuel cost basis; but its extreme versatility of application and other process benefits will often outweigh considerations of energy cost. In some instances the process itself may well dictate the use of electroheat as the only practical means of heating. There are three well established methods of electric heating for Indian industrial purposes that are commonly used.

1. Resistance Furnaces
2. Induction Furnaces
3. Arc Furnaces

3.1 RESISTANCE FURNACES

Resistance heating is usually much the cheapest method of electrical heating both as regards capital and operating costs since the equipment required is simple and the electrothermal efficiency is greater than with other forms of electric heating. This method of heating is particularly attractive where the heating current can flow directly through the workpiece or where resistance heaters can be embedded in, or maintain good contact with, solid charges of good thermal conductivity, such as metals, or be immersed with in a liquid or gas.

The electrical conductor may be either a separate heating element, conveying the energy provided by electrical dissipation to the charge by radiation and/or conduction(indirect resistance heating), or it may be the product itself, if the product is an electrical conductor at the process temperature (Direct resistance heating).

In either case there is no energy loss within the heating element, although the overall efficiency may be reduced slightly by losses through the container walls or in transformer and current feeders and thermal insulation in for

example, trace heated pipes. Overall efficiency can however be kept high (97%) by careful design and the use of fast heating cycles.

The choice of indirect heating elements is determined by the temperature and conditions in which they are made of nickel chromium alloys, silicon carbide, molybdenum, tungsten and graphite. The industrial applications of resistance heating are numerous. This paper mainly focusses on energy efficiency options of ovens.

Ovens

With designs for natural convection heat from the elements through the air surrounding the charge pieces, which are stacked inside the oven, operating temperatures upto 200 °C are obtained. With fan-assisted convection the operating temperature is raised to higher levels, 300–500°C, while allowing more precise and uniform temperatures in the charge.

Ovens may be constructed for batch operation with dimensions permitting easy access and placing of the charge pieces; metal sheathed elements or wire-wound coil elements assembled into a heater battery with forced-air blow system are used depending on size of oven and kW rating.

For applications requiring a continuous flow of work materials, e.g. vitreous enamelling, paint drying and finishing, continuous ovens using radiant heat from metal-sheathed elements or forced- air convection heating systems may be employed.

Several heat zones are normally employed to give the desired temperature gradient over the length of the oven, using thermocouples for each zone working with multipoint-recorder controlling instruments. Excess-temperature monitoring thermocouples are used to disconnect the power supply in the event of mal-operation of the normal temperature control devices.

Oven construction and design of heat-circulating systems depend largely on the kind of products that will receive the heat, i.e. shape, mass density, stacking arrangements and materials.

The energy conservation aspects of these type of furnaces include adequate insulation, proper sizing of recirculating blower motors, regular calibration of thermostatic controllers, Stacking arrangement of stock, reducing the furnace openings etc.

The case study showing the energy balance of a baking oven is shown below:

Heat supplied	=	100 %
Heat given to products	=	54 %
Convection & Radiation loss	=	14 %
Heat given to conveyor & Other losses	=	32 %

After analysing the energy balance and observing the furnace operations, the following observations and recommendations can be arrived at:

1. Effective insulation of oven
2. Replacing the circulation blower motors with lower capacity motors results in a savings of Rs. 26,000 per annum with an investment of Rs. 65,000 per annum.
3. Reducing the inlet opening area of the oven results in a saving of Rs. 8,500 per annum.

4. Avoiding the empty run of the conveyor.
5. Closing both ends of the baking oven at the end of the day resulting in a saving of Rs. 13,000 per annum.

3.2 INDUCTION FURNACES

Induction furnaces are mainly used for the melting of ferrous metals, where their efficiency can be high, but they also find application in the melting of nonferrous metals such as copper, aluminium and zinc. Induction furnaces are also used in heating of solids to achieve functions like rolling, extrusion, hardening. It is also used in conjunction with other furnaces.

There are two basic types of induction furnace, the coreless furnace, in which the induction coil is external to the crucible, and the channel furnace, in which the induction coil, suitably encased, is surrounded by the charge. In the case of the channel furnace, the induction coil is wound round a core of silicon iron laminations to concentrate the field.

The optimum choice of frequency for an induction furnace is decided by the same considerations as apply to other forms of induction heating, but in addition the degree of electromagnetic stirring required in the molten metal has to be taken into account. This stirring effect, or turbulence, is directly proportional to the power input to the furnace and inversely proportional to furnace size. For large bulk melting applications, mains frequency is the general choice, but for more specialised application higher frequencies are sometimes desirable.

Induction heating of solids

Skin effect grows with frequency, not only in the workload, but also in the wire of the coil. At high frequencies nearly all the heating occurs in the skin of the work blank. The rate of heating drops down exponentially and rapidly towards the centre. If the frequency is low, the generation of heat is also greatest at the skin and decreases exponentially towards the centre, but more gradually than it drops with high frequency.

Heat penetrates more deeply. In accordance with these facts, bars or billets of large cross section or heated with low frequency if thorough heating for forging or rolling is wanted. High frequency is used for through-heating of small of any cross section.

In the induction heating of bars or slugs with large cross section, air suffices for electrical insulation between work blank and coil, but does not furnish heat insulation. The skin of the work blank is hotter than the core. Too much heat is lost unless thermal insulation is provided. The refractory enters between the turns of the coil and holds them apart. The insulation should be thick to reduce the loss of the heat. It should be thin because magnetic flux in the refractory does not heat the work blank. A thick refractory lowers the power factor and the efficiency.

In induction heating two conflicting influences are found. If the power to the load is low (the current in the coil is weak), heating takes a long time, the temperature in the billet is uniform, but much heat is lost. If the power to the load is great (the current is heavy), little heat is lost, but the temperature in the billet is not uniform. As a rule, coils are designed for heavy current.

The capacity of a coil is expressed by the kilowatts it can absorb minus the I^2R loss in the coil. The heat in the billet at the end of the heating period is less than the heat imparted to the billet because some heat is dissipated during the heating process.

A typical energy balance for a 5 tonne mains-fed melting furnace heating a 1 tonne cold charge from 40°C to 1505°C when added to a molten charge of 4 tonne at 1505°C,and the energy balance for holding 5 tonne at 1530°C are given below:

ENERGY BALANCE OF A CORELESS INDUCTION FURNACE

LOSS	MELTING kWh/T	HOLDING kWh/T
Electrical losses		
Furnace transformer	7.2	1.8
Phase balancing circuit	4.0	0.2
P.F.correction capacitors	5.4	0.3
Water cooling losses		
Coil resistance loss	110.0	5.4
Lining conducted heat	61.0	15.4
Furnace heat losses	37.0	6.3
Other losses	11.0	0.6
Useful heat	376.0	—
Total	612.0	30.0

FACTORS TO BE CONSIDERED FOR ENERGY EFFICIENCY

1. Holding periods have to kept to minimum as the cooling water losses are very high with longer holding periods.
2. Tap-to-tap time has to be minimised to reduce the radiation and convection losses and effective capacity utilisation.
3. Pyrometers have to be used to measure the accurate temperature of melting to avoid the unnecessary superheating of the liquid metal.
4. Opening of furnace lids, slagging door etc., are to be minimised.
5. Possibility of charge compacting and preheating has to be explored.
6. Cooling water inlet , outlet temperatures and flow rates are to be monitored to assess the condition of the furnace refractory lining and the coil losses.
7. For the manufacture of a particular type of casting or for mild steel ingots. The melting capacity of the furnace should be precisely determined. Because too large a capacity than needed would mean very high heat losses, because of large holding time (the losses occurring in radiation and in cooling water losses). Large holding periods would also mean a large quantity of superheat. If capacity utilisation rates are to be high, the quantity of super heating necessary will also reduce.
8. The capacity of the furnace is also determined by the size of casting and the capacity of the plant.
9. For a maximising load factor (and by reducing the cost of energy per unit of output), production rates and furnace capacities should be judiciously matched.
10. For performance monitoring of the furnace, performance index (kg/h at a specified temperature/ kVA) should be maintained on a regular basis.

HEAT BALANCE FOR INDUCTION FURNACE (CASE STUDY)

1. Useful heat	=	38%
2. Radiation Loss	=	9%
3. Cooling water loss	=	40%
4. Slag & other losses	=	13%

Observations

1. Cooling water losses very high
2. High holding time about 45 minutes after melting
3. High superheating to around 1680°C
4. Low capacity utilisation

Recommendations

1. Refractory insulation to be checked; for properly laid crucible the losses including in cooling water could be brought down to around 27%.
2. Holding time could be avoided if the number of moulds could be increased to match the capacity of furnace. This would also require the additional leakes. Presently about three chargers are prepared by one ladle. This will bring down the radiation as well as the cooling water losses. About seven percent decrease in energy consumption is expected.
3. Provide for covering the top after charging has been completed.

HEAT BALANCE AFTER (EXPECTED) IMPROVEMENTS

1. Useful heat	=	56%
2. Radiation loss	=	4%
3. Cooling water	=	27%
4. Slag and other losses	=	13%

The total savings in this case was expected to be around Rs. 3 Lakhs per annum.

3.3 ELECTRIC ARC FURNACE (EAF)

The most common type of arc furnace is the 3-phase direct arc furnace consisting of three symmetrically placed carbon electrodes each of which is connected to one phase of the supply system. Arcs are struck and maintained between the electrodes and the metal charge, which is heated by radiation from the arcs and reradiation from the furnace refractory lining as well as by the passage of the arc currents through the charge.

The characteristics of the arc call for special current regulators and sometimes series reactors to limit current surgs when the electrodes tough the charge. In the initial stages of striking arc, the arc is rather erratic but as metal ions begin to enter the plasma it's stability improves. Steelmaking in Electric Arc Furnace (EAF) is the phenomenon of this century and has grown very rapidly to become an established technology because of

a) Investment cost is low

b) Low gestation period

c) Low specific energy consumption (2.3 Gcal/T) compared to other processes (5.5 Gcal/T)

d) Flexibility in operation as it can handle any kind of scrap of any shape and size.

e) Chemistry of tapped metal can be adjusted easily.

The unit capacity of EAF in India is about 4 to 30T, where as in the western countries the average tapped weight is about 60 tonnes. The capacity utilisation of EAF is between 55–90 %. The bigger units (15 T) adopting modern technologies such as ladle refining and oxygen lancing have a higher capacity utilisation compared to smaller units. Exhibit–12 gives the effect of furnace size on power consumption.

The energy balance of the arc gives that 72.5% of the electric power of the arc is transferred into the melt, 14.5 % goes into the electrode, and 13 % to the furnace wall. The proportions depend on the arc length and the slag thickness.

FACTORS FOR ENERGY EFFICIENCY

Control of power input

The best use of power in the meltdown depends on two basic facts. The heat produced per unit of power consumed is a function of the characteristics of the electrical circuit and is controllable in considerable degree by selection of those voltage current relationships which will keep the power factor of the circuit within certain narrow limits.

Only that part of the heat is useful which is absorbed by the charge. Excess heat is reflected to the furnace lining and roof, this is both wasteful and damaging.

Since resistive load is the only heat source in the furnace circuit, it is desirable to have all the resistance inside the furnace where the heat is required and nowhere else in the furnace circuit. A high P.F. is not necessarily indication of an efficient circuit design. A high resistance in the circuit due to insufficient material in the conductors can raise the P.F. substantially. A high P.F. so obtained is not a measure of high efficiency.

Nature and quality of scrap used

The metallurgical condition, density and cleanness of any ferrous material charged into an arc furnace affects the energy balance either directly or indirectly. For example, the direct effect of 1% gangue, moisture or iron oxide (Fe_2O_3) within the charge on energy consumption results in increase in energy consumption of 10kWh/T, 18kWh/T and 15kWh/T respectively.

The indirect effect of scrap density on energy consumption has been established on trials. As might be expected, a maximum of two baskets per charge is desired but, because of variations in both availability and density of scrap, this is not always possible. If as a result of these variations a third basket has to be charged, then the tap-to-tap time is increased by 4–6 min, which in turn leads to an increased consumption of 5–10 kWh/LMT.

Apart from increasing the density of the scrap the beneficiation also has a direct effect on energy consumption. In addition, the emphasis placed on the need to reduce the risk of furnace down-time due to damage to the furnace by the inclusion of explosive material, or to the electrodes by the inclusion of electrically non-conducting material, has both a direct and indirect effect on the total energy consumption.

Use of blast furnace plate iron

Energy balance shows that approximately 10 % of the energy input is obtained from exothermic reactions. This arises as a result of the oxidation of carbon, silicon, phosphorous and manganese dissolved in the liquid iron. After allowances have been made to account for the heat required to raise the oxygen to steelmaking temperatures, the energy gains are shown in Exhibit–13.

The availability with in India of blast furnace plate iron presents an opportunity for such selection,and experience has confirmed that energy consumption can be reduced at the expense of oxygen consumption (Exhibit–14).

Clearly the deliberate addition of coke, silicon carbide coke and ferro-silicon to the charge could result in energy savings. Experience indicated that savings in the region of 10 kWh/LMT can be achieved, but this does not take account of the energy that may have been expended in producing the raw material in question.

Lime addition

Usually the limestone is added to the liquid steel as a slagging material. The limestone has to first decompose to lime(CaO) which in fact is the fluxing agent for slagging. Since the decomposition is an endothermic reaction this brings in two additional heat losses namely, the endothermic heat required for the decomposition of $CaCo_3$ and the heat taken by the Co_2 gas evolved. Experience shows that using burnt lime directly is going to result in 100 % cost savings compared to using limestone. It is an established fact that a reduction of 1 tonne in the lime added during single slag steelmaking does decrease energy consumption by up to 10 kWh/LMT. In general terms, the magnitude of the saving on any given cast depends, as would be expected, on the tightness of the sulphur specification to be met.

Oxygen Lancing Practice

Chemical energy can make a significant contribution to the energy balance. It is essential that the oxygen lancing practice be optimized. Lance angle and position, blowing rate, infiltration rates and fume extraction conditions can affect energy consumption in addition to electrode and refractory costs.

Furnace Pressure

The pressure maintained within the furnace controls both the rate at which waste gases are extracted and the ingress of air through slag doors, etc. Currently, the general opinion is that a slight positive pressure at roof level minimizes the effect on energy consumption, although little quantitative work has been done to confirm this.

Use of Economisers

The gaps between the electrodes and the three ports in the roof are obvious positions at which energy can be lost. Such losses are minimized by the use of economizers which restrict the ingress of air through the port, although their prime purpose is to minimize erosion of the port itself. Obviously, the effectiveness of these devices is dependent on good and efficient maintenance.

Oxy-fuel burners

The use of oxy-fuel burners to augment the energy input and to reduce the conversion costs in basket-feed practices has received considerable attention. Usually, three burners are sited in the side walls at positions which are selected to enhance scrap melting without undue effect on the electrode consumption.

Correct burner design, positioning, angle and method of utilisation are critical if maximum energy savings are to be obtained.

Scrap Preheating

The arc furnaces discharge large quantities of hot gases bearing considerable fume and dust in the shop floor. The dusty exhaust gases carry about 15–20% of the total energy input to EAF. By using these gases to preheat the scrap charge, considerable savings in energy input to the EAF can be achieved. The cooled exhaust gases can be easily handed by dust control equipments. Also the scrap charge acts as an arrester for the dust in the gases. Extensive use of oxygen to assist melting have lead to increasing furnace gas volume thereby increasing the heat loss in gases. Exhibit–15 shows the effect of scrap preheating on energy.

Various types of scrap preheaters include conventional bucket preheater, vessel type preheater and special bucket preheater.

3.4 STANDARD PRACTICES TO MINIMISE ENERGY CONSUMPTION

The elimination of delays is as vital to profitable operation as the efficient consumption of electric power is essential that the entire active furnace life be utilised to the best advantage. Therefore, the operations for furnace preparation and repair, charging , melting refining, finishing, and tapping all are planned by the furnace operations so that with the best overall performance a heat meeting the customer's requirement can be produced at minimum cost.

CHARGING

Efficient charging and meltdown requires the observance of certain rules which may be as follows:

1. Initial charge must be of sufficient density to achieve the required heat tonnage with a minimum number of recharges after the initial meltdown starts.
2. The charge should be carefully selected, in case of alloy steel production, to result in a melt down bath analysis which is close to the customer's product specifications. Carbon in the charge may be adjusted to melt close for the common steels, or considerably above for higher quality, in order to gain full benefit of the carbon boil.
3. The charge should exclude, as completely as possible, non- conductive material to avoid the breakage of electrodes, as they strike these materials.
4. The scrap quality and the desired product analysis determine the addition of lime to be charged.
5. Placement of the charge in the furnace must also be planned to attain efficiency in charging and meltdown with particular emphasis upon the maximum degree of heat absorption.

5a. A small quantity of light stamping scrap is positioned to cushion the impact of the heavier pieces of scrap as they fall into the furnace

5b. Heavy scrap is placed in the centre of the charge and should be located within the electrode circle.

5c. A sufficient quantity of medium and low density scrap is added on top of the heavier pieces to complete the furnace charge.

MELTDOWN

The ideal method of melting would be to heat the charge as evenly as possible from the centre and all other exposed areas. A practical method for this is as follows:

1. Lower the electrodes by push button as closely as is possible to the charge to reduce the time required for the automatic control to lower the electrodes and strike the initial arc.

2. Select suitable voltage levels so as to inject enough energy into the arc to allow the electrodes to bore down into the charge until they approach the heavy scrap at the furnace bottom. This practice permits the greatest absorption of the arc energy by the charge and promotes the economic use of electric power.

3. Once the primary bath has been formed at the bottom of the furnace the scrap is melted by heat transmitting through the steel bath as well. Melting continues at this power level until the bath temperature requires this power. In some cases, it may be necessary to cut off power during this late melting period to raise the electrodes and to push any scrap which may have clung to the side walls above the bath.

4. If the scrap is not dense enough to get the required charge weight into the furnace in the initial charge the remaining of the scrap is charged as soon as the scrap is melted to the level mass.

TYPICAL DELAYS IN MELTDOWN OF EAF THAT AFFECTS ENERGY

1. Delays in crane service or in scrap delivery shutdowns for power demand, and mechanical failures affect seriously the melting procedure.

2. Scrap charge of incorrect chemical analysis sometimes necessitates changing the furnace schedules and melting to a different specifications, so that the analysis resulting from the faulty scrap delivery may be utilised.

3. Heavy pieces of scrap placed along the sidewalls of the furnace may fall against and break an electrode during meltdown.

4. An electrode may be broken by contact with any large concentration of insulating material in the charge, such as limestone, since the electrode drive will continue to exert downward force as long as current in that leg of the circuit is low.

5. Errors in selection of power input levels may result in slow melting rates and damage to the furnace lining and roof. Another result may be bridging of solid steel above the melt as the electrodes are boring in, a possible cause of electrode breakage.

3.5 ENERGY BALANCE OF ARC FURNACE (CASE STUDY)

The energy balance of a 9 tonne electric arc furnace is shown in Exhibit–16 with the representation of sankey diagram in Exhibit–16a.

The careful observation of furnace operation and energy balance resulted in the following recommendations:

1. Use of burnt lime instead of lime stone would result in a saving of around Rs. 3 lakhs per annum.

2. Increasing oxygen lancing results in a net saving of around Rs. 46,000 per annum.

3. Preheating of the scrap was estimated to save around 40–50 kWh/LMT.

EXHIBIT 1

TYPICAL THERMAL EFFICIENCIES

	Equipment Type	Typical Thermal Efficiencies (In the Field)
1.	Electric Utility Boilers	85 - 90%
2.	Industrial Boilers (Steam)	74 - 82%
	(HPHW)	76 - 84%
3.	Ovens	
	A. Indirect fired ovens 20°C-370°C	35 - 40%
	B. Direct fired ovens 20°C-370°C	35 - 45%
4.	Low Temperature Furnaces	
	A. 540-980°C (Batch)	20 - 30%
	B. 540-980°C (Continuous)	15 - 25%
	C. Coil Anneal (Bell) Radiant Tube	4 - 7%
	D. Strip Anneal Muffle	7 - 12%
5	High Temperature Furnaces	
	A Slot Forge	5 - 12%
	B Pusher, roll down, or Rotary	7 - 14%
	C Batch Forge	5 - 10%
	D Car Bottom	7 - 12%
6	Continuous Kilns	
	A Hoffmann	25 - 93%
	B Tunnel	21 - 82%
	C Transverse-arch Annular	26 - 96%
7	Dryers (brick)	
	A hot-floor	14 - 25%
	B Tunnel	15 - 53%
	C Chamber	20 - 53%

TYPE	OIL							GAS		REMARKS
	PRESSURE ATOMISING				OTHER TYPES OF ATOMISATION					
	SIMPLEX	DUPLEX	SPILL	STEAM/OR AIR	ROTARY CUP	MPA	LPA	NOZZLE MIX	PRE-MIX	
Characteristics / Main Applications	A-H	E	C-H	A-D & F-H	A-H	C,E-H	F-H	A-H	F-H	A Large Water Tube Boilers >30MW B Medium Water Tube Boilers <30MW C Small Water Tube Boilers <10MW D Shell Type Boilers <15MW E Shell Type Boilers <5MW F Furnaces G Dryers H Incinerators, etc
Flame Characteristics	Normally soft wide angled flames			Capable of wide variation in shape and intensity		High Intensity flame	Soft flame	Luminous to non-luminous	Non-Luminous	Can be varied considerably depending on register Δp and combustion intensity
Flame Shape-included angle	>70	>70	>70	50-130	50-160	30-100	>50	—	—	
Atomising Viscosity Redwood No 1	<100	<100	<100	<100	<300	<150	<100	—	—	For distillate fuels preheating not necessary
Kinematic (centistrokes)	<24	<24	<24	<24	<74	<37	<24	—	—	
Turndown Ratio (T/D)	<3 2	8 1	8	10 1	10 1	5 1	4 1	10 1	3 1	1 Wide variations possible beyond figures given 2 Dual fuel firing Turndown limited to oil T/D capability
Average atomising or Discharge Pressures kPa	>1034	>1034	>1034	>206	>170	>206	>206	>1 2	>0 5	With some types discharge pressure has no influence on atomisation
Primary Air Pres kPa	Normally supplied with secondary air			>100	2 5-12	20-103	2 5-8 7	>25	<2 5	With certain burner types primary air is not necessarily used for atomisation
Primary Air Vol %				<5	3-20	<10	>25	>10	>50	
Normal Possible Air Pre-Heat °C	← 350 →				<93	← 350 →		—	—	High pre-heat normally used only for process applications
Normal Thermal Input MW	<120	<5	<120		<50	<10	<5	<100	<5	Values given to conform to modern industrial applications
Typical Combustion Intensities kW/m³	← <1500 →				<3100	<4100	<1040	<3100	<4100	The choice of burner depends on matching combustion intensity to combustion space
Draught (B/F/I) Balanced/Forced/Induced	← B F or I →						B,F or I	B or I	B or I	Modern practice favours forced draught & pressurized combustion
Dual Fuel Capability Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Changeover may not necessarily be automatic

Note The above are general particulars and as such do not preclude the existence of special burners with different characteristics In Great Britain burners normally manufactured to conform to BS 799 BS CP 3002, H M Factory Technical Data Note No 25 and British Gas Corporation Standards and Codes of Practice

EXHIBIT 2

GENERAL CHARACTERISTICS OF THE PRINCIPAL TYPES OF AUTOMATIC INDUSTRIAL OIL, GAS & DUAL FUEL BURNERS

Exhibit 3.

**Effect of Construction on Furnace Wall
Heat Transmission and Storage Losses**

Furnace Temperature 1500°C

Wall Construction					
Firebrick	340mm	230mm	115mm	-	-
Super Hot Face Insulation	-	-	-	230mm	115mm
Backing Insulation	-	115mm	230mm	-	230mm

Continuous Operation

Heat Loss kWh/m_2					
Conduction	9150	3850	2650	4038	2145
Storage	160	176	114	35	50
Total over 2000 h	9310	4026	2764	4073	2195
% Reduction in Total Heat Loss		56.8	70.3	56.3	76.4

Intermittent Operation 5 - 10 h shifts/wk.

Heat Loss kWh/m^2					
Conduction	91	76	60	79	44
Storage	331	271	167	91	79
Total over one week	422	347	227	170	123
% Reduction in Total Heat Loss		17.9	46.3	59.7	70.9

Exhibit-4

– EFFECT OF HEARTH LOADING ON FURNACE PERFORMANCE

Slot Type Reheating Furnace. Hearth Area $1.4m^2$.
Waste Gas 1300°C 10% Excess Air
Heat availability 35%
Final Stock Temperature 1250°C

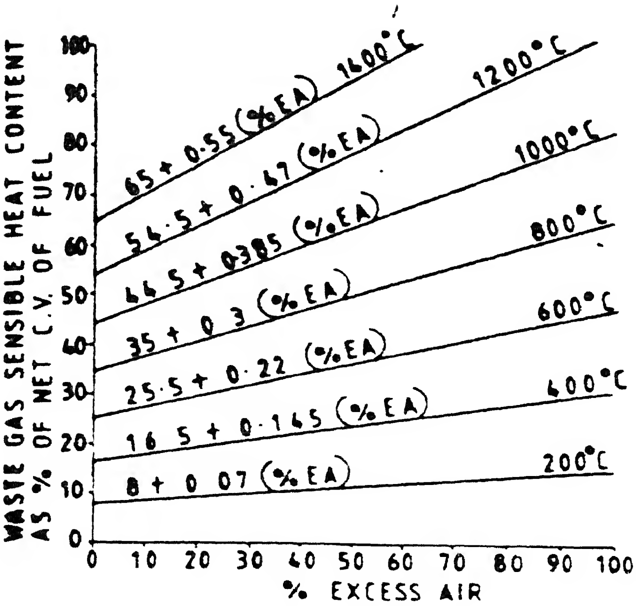
	Hearth Loading Kg/m^2h 98	146	244	366
Steel output Kg/h	136	204	340	510
Heat to steel KWh/h	3	46	77	715
Heat to furnace structure KWh/h	80	80	80	80
Heat input required (at 35% availability KWh/h	314	358	446	556
Fuel consumption				
Actual litres per hour	30	35	43	53
Specific litres/tonne steel	220	172	126	104
Fuel and financial saving per ton steel processed %		24.4	43.2	52.8

At the lowest loading quoted, production is twice as expensive in terms of fuel as it is at the highest loading.

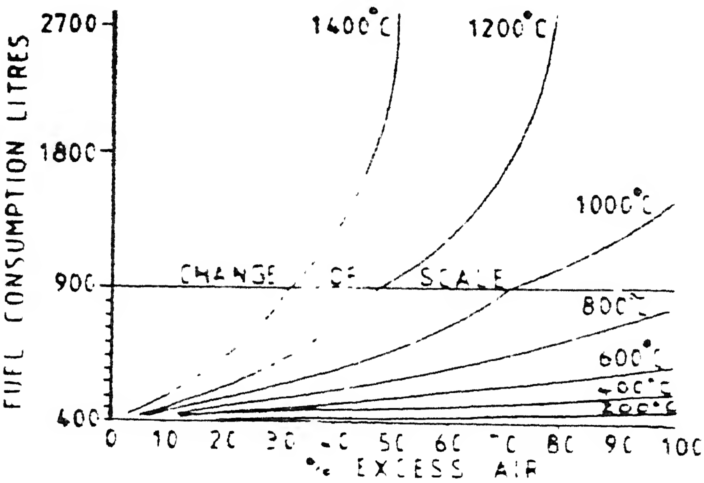
Typical good practice loading rates for various types of furnace would be

Heat Treatment	145	195 Kg/m^2h
Annealing	195	290 Kg/m^2h
Drop Stamping and Forging	290	390 Kg/m^2h
Continuous Reheating	340	490 Kg/m^2h

Exhibit-5



– VARIATION OF WASTE GAS NET HEAT CONTENT WITH EXCESS AIR CONTENT AND TEMPERATURE



– EFFECT OF EXCESS AIR CONTENT ON FUEL CONSUMPTION

Exhibit -6

POTENTIAL SAVINGS BY COMBUSTION AIR PREHEATING

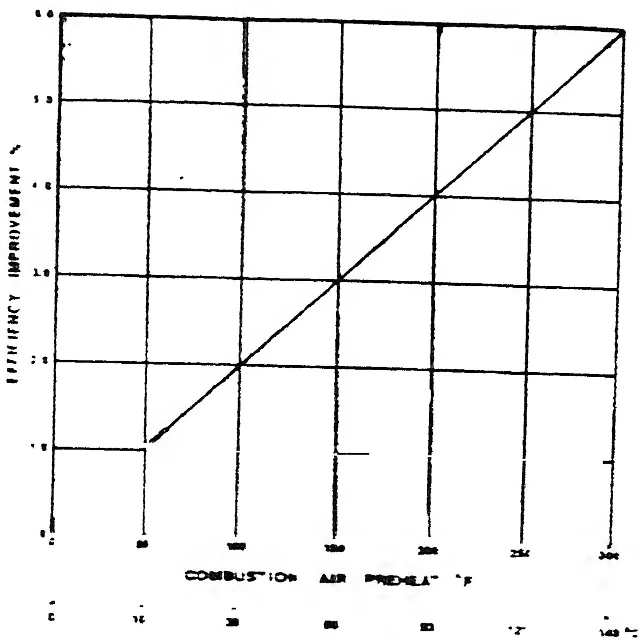


EXHIBIT 7 - A REVIEW OF HEAT RECOVERY DEVICES

Device	Description	Typical Applications	Comments
Gas to gas heat exchangers			
Plate heat exchangers	Gas streams separated by parallel or dimpled plates mainly in cross flow form. Materials frequently aluminium or coated aluminium but paper and stainless steel also.	Ventilation and Lower Temperatuer Process System.	Handle large volumes at low pressures. No cross contamination and good efficiency. Mostly applied below 200°C but some units applied up to 600°C. Retro fitting can be difficult.
Heat pipes	A sealed tube contains a wick, lining the inside wall, plus a working fluid. Opposite ends of tube are positioned in heated and cooled gas streams and heat is transferred by evaporation/cooling.	Process Systems.	Normally limited to max. temp of 400°C but higher in some cases. Efficiencies only fair (about 60%). Fairly high costs. No moving parts, no maintenance
Run around coil	Liquid circulated in closed circuit pipe system to coils positioned in supply and exhaust gas streams.	Ventilation and Lower Temperature Process Systems.	Low capital cost and often suited to retrofitting. Normally applied below 200°C and operating efficiencies normally between 40 and 60%.
Shell tube heat exchangers	Gases flowing through tubes give up heat to gas flowing through surrounding shell.	Process Systems	Often made on a one off basis to suit particular requirements. Bulky.
Gas to liquid heat exchangers			
Waste heat recovery boilers	Similar to conventional boilers but mostly without first radiant heat transfer pass. Designed for lower gas entry temperatures than conventional boilers hence larger sizes.	Process and Incineration waste gases.	Gas entry temperatures normally above 400°C and sizes above 200 kW. Clean gases required to obviate frequent cleaning.
Flue economisers	Finned or plain tube bundles in boiler flue or process gas streams. Heat recovered as hot water and units may have integrated bypass.	Boiler and Process Waste Gases.	Wide range of sizes covering most commercial and industrial boiler applications. Can suffer from cold spots leading to corrosion.
Fluidised bed	Gases pass through a shallow fluidised bed and heat hot water or steam in finned or plain tubes.	Fouled gas streams up to 1000°C.	Compact and self cleaning but not yet fully developed.

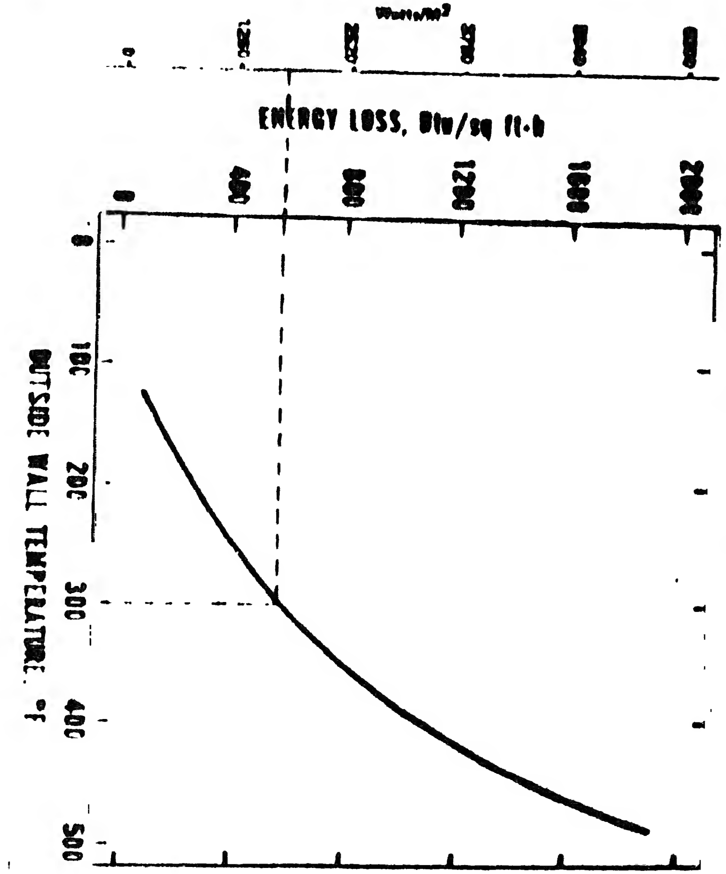
Liquid to liquid heat exchangers			
Shell tube heat exchangers	Liquid flowing through tube bundle conveys heat to surrounding liquid contained in a shell.	Process heat recovery	Efficiency limited by tube heat transfer coefficients but available for wide range of temperatures and pressures. Low cost, simple design but can be bulky
Plate heat exchangers	Liquids separated by flat or dimpled plates to give contra flow heat exchange between the two fluids.	Process Heat Recovery	Maximum temperatures below 500°C and maximum pressures about 20 bar. Temperatures can be limited by the seals available to suit the fluid. High efficiency, low capital cost.
Recuperators (also see diagram of possible savings by preheating air)			
Recuperative burners	Flue gases used to preheat burner combustion air. Recuperator may be integral with burner or separately positioned.	Furnaces and Processes above 600°C.	Clean gases required to avoid fouling and/or corrosion of the heat exchanger. Materials limit applications to a maximum of about 1400°C.
Spray recuperator	Clean non-corrosive exhaust gases in contra-flow with sprayed water to give hot water heat recovery.	Boiler and Process flue Gases.	Important that gases are clean, otherwise water is contaminated and secondary heat exchanger must be used. Good heat transfer. Simple.
Falling cloud recuperator	Exhaust gases in contra-flow with solid particles which fall to a fluidised bed heat exchanger to provide steam or hot water.	Hot dirty gases.	A new device now being proved. Should provide heat recovery to dirty gases.
Regenerators			
Heat wheels	A permeable matrix in the form of a disc slowly rotates. Half of the disc is in hot gas stream and half in a cooler gas stream. The gases pass through the matrix of the disc.	Ventilation systems and clean lower temperature process gases.	Compact dimensions and low pressure drop combined with high efficiency. Cross contamination occurs and initial costs can be high.
Regenerative burners	When burner is not firing, hot exhaust gases flow through the burner and heat a ceramic heat sink. When burner fires, combustion air is preheated in the ceramic heat sink.	High temperature process work	Only just commercially available but promises high efficiencies and suitability to high temperature clean gases.
Refractory regenerators	Refractory lined ducts alternate as exhaust and combustion air ducts.	Higher temperature processes, many continuous.	A bulky form of heat exchanger but capable of use with dirty and/or corrosive gases. Normally forms a part of the appliance.

EXHIBIT 7 Continued

Heat pumps			
Vapour compression type	Closed circuit system in which vapour is compressed before condensing to release heat. Then liquid absorbs heat in an evaporator before returning to the compressor.	Space heating/air conditioning and drying.	Uses low grade heat and therefore applied to low temperatures (up to 100°C) sizes range from few kW to several MW. Compressor shaft power provided by either electric motor or gas engine. Waste heat from latter can be usefully employed.
Absorption type	As above but compressor replaced by circulating pump and heat used to vaporise a refrigerant/absorbent solution.	As above.	Lower operating and maintenance costs than above. High efficiency potential if heating input re-used.

Exhibit - 8

ENERGY LOSS THROUGH FURNACE WALLS



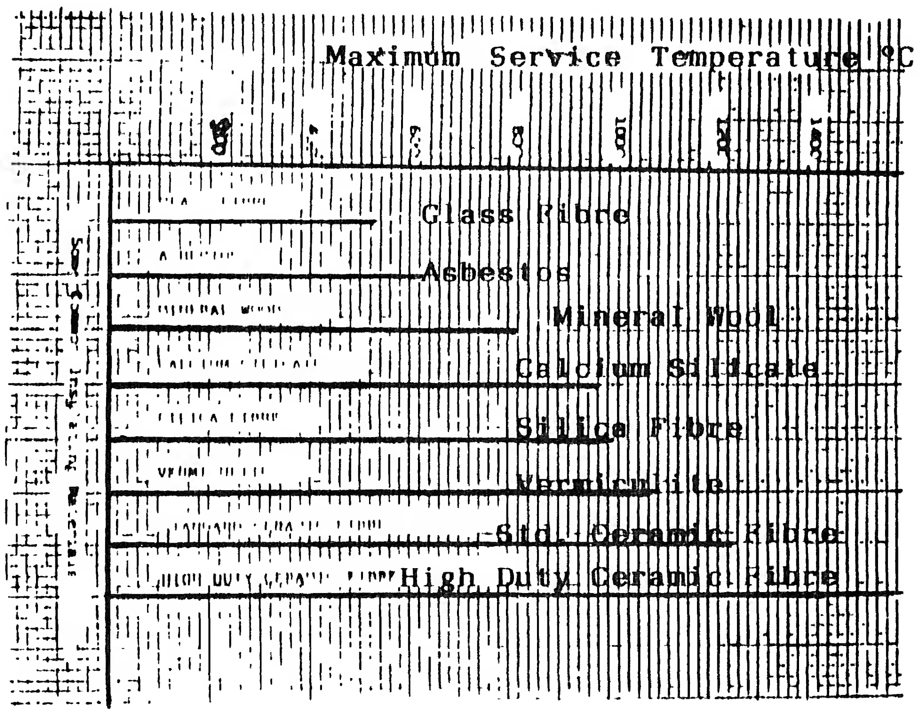
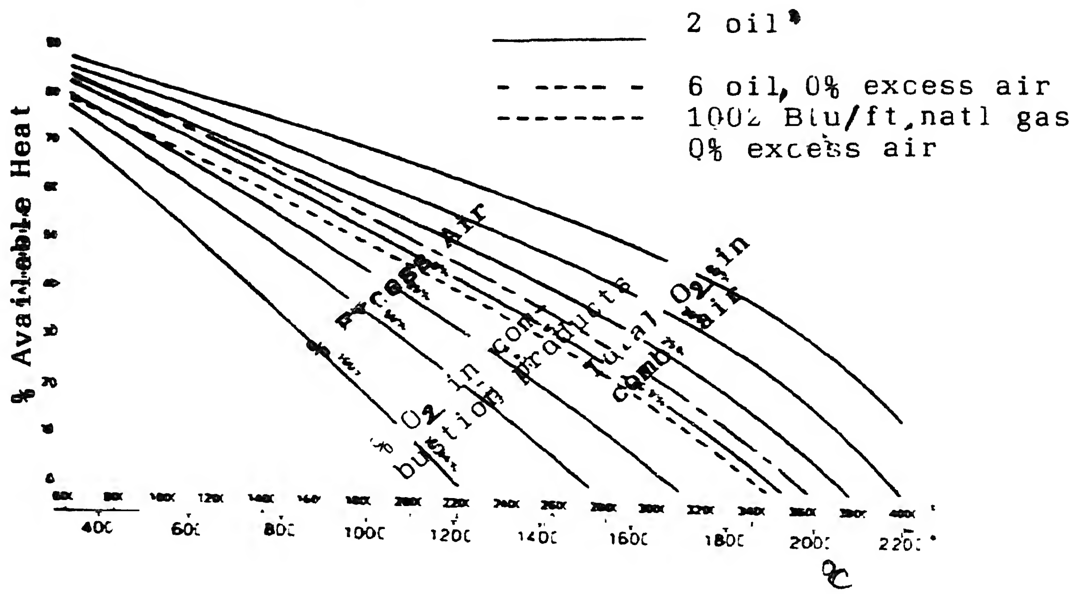


EXHIBIT 9

OPERATING TEMPERATURE OF SOME COMMON INSULATING MATERIALS

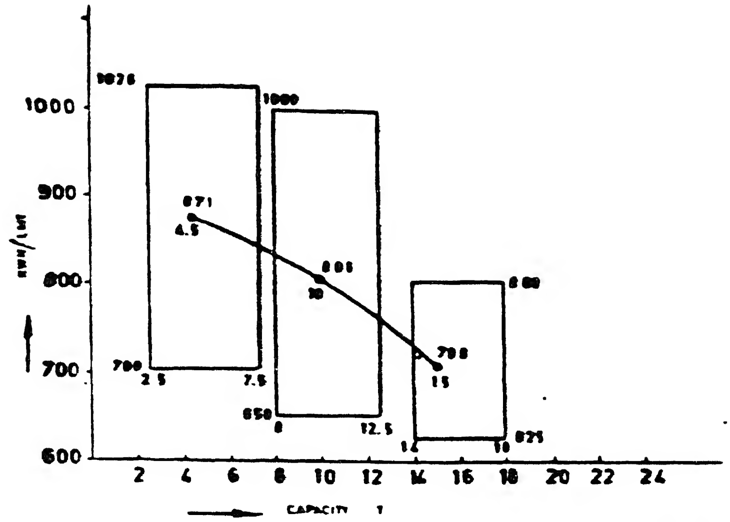
Exhibit -10

SAVINGS POSSIBLE BY OXYGEN ENRICHMENT



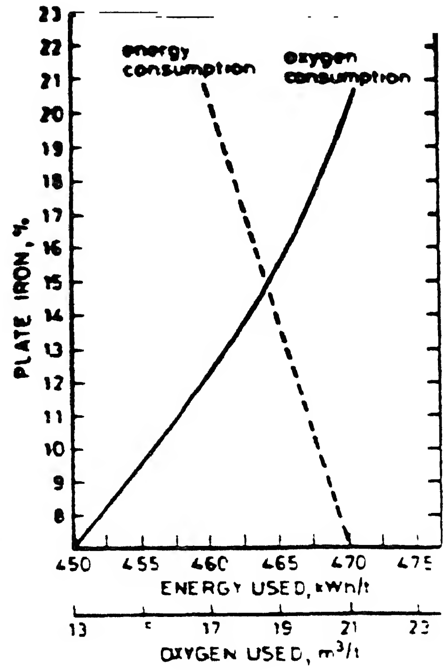
ENERGY INPUT	MJ	%	ENERGY OUTPUT	MJ	%
Heat supplied	103300	100	Heat absorbed by billets	37400	36.20
			Heat loss through walls	12050	11.70
			Heat loss through openings	2879	2.80
			Heat loss in flue gas	46040	44.60
			Unaccounted losses	4931	4.70
	103300	100		103300	100.00

Exhibit-11 ENERGY BALANCE FOR THE 10 T/hr BILLET REHEATING FURNACES



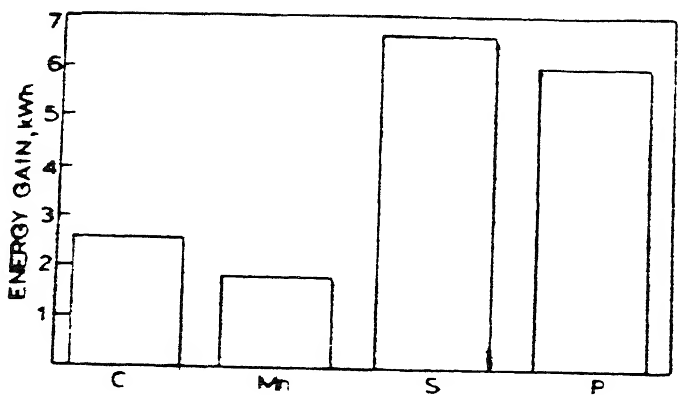
EFFECT OF FURNACE SIZE ON POWER CONSUMPTION

EXHIBIT 12



Effect of varying plate iron content with charge mix on energy and oxygen consumption

EXHIBIT 14



Energy gain per kg of element in charge mix

EXHIBIT 13

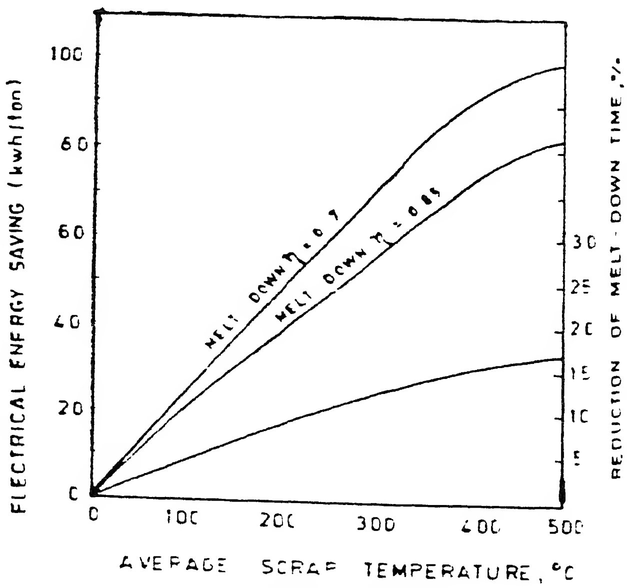


EXHIBIT 15

ENERGY INPUT	MJ/LMT	kWh/LMT	%
Electrical energy	2709	750	82.22
Electrode oxidation	110	30.5	3.34
Heat of reaction	473.98	131.7	14.44
Total	3292.98	91212	100.00
ENERGY OUTPUT	MJ/LMT	kWh/LMT	%
Heat in liquid steel	1409	390.1	42.80
Heat in slag	123	34.1	3.74
Heat in evolged gases	650	181	19.80
Heat loss through walls	64.8	18	1.97
Heat loss in cooling water	927	256.7	28.1
Electrode + Electrical losses	119.18	32.3	3.59
TOTAL	3292.98	912.2	100.00

Exhibit 16 ENERGY BALANCE FOR THE 9 T EAF

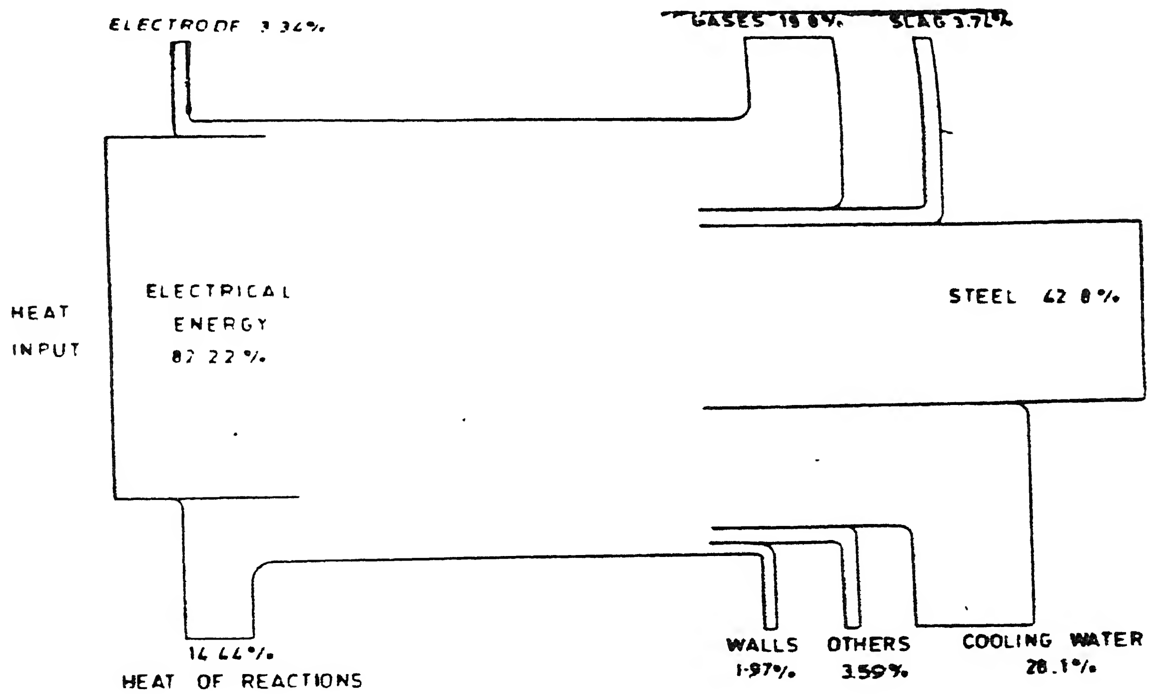


Exhibit 16A SANKEY DIAGRAM FOR THE 9T ELECTRIC ARC FURNACE

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